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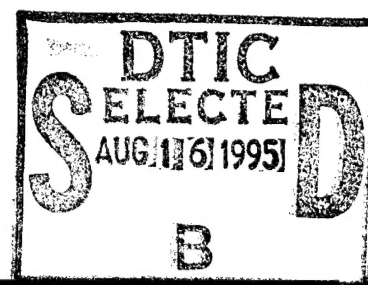
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REPORT NO _____

**Thermal and Moisture Properties of
Mission Oriented Protective Posture (MOPP) Clothing
at High Altitude**

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

August 1995



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**UNITED STATES ARMY
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The effects of hypobaria on the thermal insulative properties and heat transfer characteristics of the BDU and BDO in all four MOPP configurations were examined. Barometric pressure of 429 Torr (mmHg) was created in the USARIEM hypobaric chamber. The sea level environment was used as a baseline condition. Skin, clothing, and dew point temperatures were measured on subjects standing and walking on a treadmill. We found that hypobaria had minimal effect on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not appreciably affect clothing insulation values. For the more insulative BDO, an average difference of 0.2 clo was found between the sea level and the altitude environments. The BDO MOPP level increase, from MOPP0 (BDU) to MOPP4, was also accompanied by a gradual increase in the average skin temperature difference between sea level and altitude environments. An interesting outcome of clothing insulation was that it segregated, thermally, the skin surface from the clothing surface. At one site, the heat transfer processes operated almost independently from the other site. As a result, in hypobaric environment, the skin temperature was found to be lower, but the clothing temperature higher, than at sea level.

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Mission Oriented Protective Posture (MOPP) Clothing
at High Altitude**

by

S. KW. Chang, W. R. Santee, L. A. Blanchard, and R. R. Gonzalez

AUGUST 1995

**U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
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EXECUTIVE SUMMARY

Clothing insulation is the result of complex interactions between heat transfer mechanisms and clothing material thermal resistances. The effects of hypobaria on the thermal insulative properties and heat transfer characteristics of the U.S. Army battledress uniform (BDU) and U.S. Army chemical protective overgarment (BDO) in all four Mission Oriented Protective Posture (MOPP) configurations were examined. Barometric pressure of 429 Torr (mmHg), comparable to the condition at terrestrial elevation of 4,570 m (15,000 ft) above sea level was created in the U.S. Army Research Institute of Environmental Medicine (USARIEM) hypobaric chamber. The sea level environment was used as a baseline condition. Skin, clothing, and dew point temperatures were measured on subjects standing and walking on a treadmill.

We found that hypobaria had minimal effect on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not appreciably affect clothing insulation values. For the more insulative BDO, an average difference of 0.2 clo ($\text{clo} = 0.155 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$) was found between the sea level and the altitude environments. The MOPP level increase, from MOPP0 (BDU) to BDO MOPP4, was also accompanied by a gradual increase in the average skin temperature difference between sea level and altitude environments.

An interesting outcome of clothing insulation was that it very effectively isolated, thermally, the skin surface from the clothing surface. At one site, the heat transfer processes operated almost independently from the other site. At the skin surface, evaporation was the dominant process, while at the outer clothing surface, convection dominated. At higher altitude, enhanced evaporative transfer resulted in a lower skin temperature, while reduced convection impeded heat dissipation from clothing surface to the ambient environment, hence elevating the clothing temperature. Therefore, in hypobaric environment, the skin temperature was found to be lower, but the clothing temperature higher, than at sea level.

INTRODUCTION

This study examined the effect of hypobaria on the thermal insulative properties, and heat transfer and moisture permeability characteristics of U.S. Army Battledress Uniform (BDU) and U.S. Army chemical protective Battledress Overgarment (BDO) in all four Mission Oriented Protective Posture (MOPP) configurations. It is known that adding the layers of BDO over the BDU increases the risk of heat stress. MOPP increases the possibility of heat casualties and degrades the soldiers' performance [Field Manual 3-4]. MOPP restricts the body's natural cooling mechanisms of convective and evaporative heat loss because of its high thermal insulation and low water vapor permeability. Moreover, when a soldier is required to perform physical activity, it adds to the body's heat production, and further aggravates the strain imposed by the MOPP suits.

Higher terrestrial elevations adds another variable to the thermal insulative property evaluation of BDU and BDO. The reduction in barometric pressure (P_b) at higher elevations alters the heat transfer mechanisms that affect clothing insulation. P_b has pronounced effects on air density and mass diffusivity, which in turn change the convective and evaporative heat transfer processes. It is known that as P_b decreases, convective heat transfer diminishes [Chang et al. 1990]. Also, the evaporative transfer mechanism appears to be enhanced [Gonzalez et al. 1985]. While the evaporative heat transfer does not alter clothing insulation directly, evaporative heat loss does affect skin and clothing temperatures, thus indirectly influencing clothing insulation. The efficacy of evaporative heat transfer increases with elevations in altitude. Furthermore, insulation of air, trapped between clothing layers and at the clothing-skin boundary layer, increases with decreasing P_b [Gonzalez, 1987]. However, the combined or net effects on clothing insulation by these P_b -mediated changes are not presently known and have not been studied thoroughly. This study examines, quantitatively, the hypobaric effect on the insulative properties of BDU and BDO, and its potential impact on the soldier's performance and well-being.

METHODS

CHAMBER

The U.S. Army Research Institute of Environmental Medicine (USARIEM) hypobaric chamber was used to simulate a terrestrial altitude of 4,570 m (15,000 ft) above sea level. The chamber simulated this high altitude environment by decreasing the ambient atmospheric pressure to 429 ± 1 Torr (mmHg). The control baseline studies were conducted at sea level, 760 ± 10 Torr atmospheric pressure (sea level barometric pressure at USARIEM on the test days) in the same chamber. The ambient temperature within the chamber was maintained at 22.0°C , with relative humidity at 50%. The wind speed was maintained at 1.0 m/s with the aid of a circulating fan. The air velocity within the chamber was measured with a cup anemometer. The chamber temperature was measured at two points (on opposite sides of the treadmill) with copper-constantan thermocouples.

SUBJECTS

Eight males, between the ages of 18 to 23, served as volunteer subjects. The volunteers received a verbal briefing on the purpose, procedures and risks of the study, and each signed an informed consent agreement. Each volunteer received a medical clearance from a medical officer. All testing procedures conformed to the U.S. Army Regulation AR 70-25, Use of Volunteers for Research.

The physical characteristics of average height, weight, body (Dubois) surface area, and maximum $\dot{V}\text{O}_2$ of the subjects are shown below ($\dot{V}\text{O}_2$ data extracted from the subjects' recent historical database).

| <u>Height (m)</u> | <u>Weight (kg)</u> | <u>Body Surface Area (m^2)</u> | <u>Maximum $\dot{V}\text{O}_2$ (l/min)</u> |
|-------------------|--------------------|--|---|
| 1.77 ± 0.11 | 77.6 ± 9.6 | 1.95 ± 0.18 | 4.28 ± 0.53 |

CLOTHING ENSEMBLES

The U.S. Army temperate zone BDU consists of a coat and trousers. The uniform is loose fitting to allow body ventilation. The material is a 50/50 nylon/cotton twill, weighing 234 g/m^2 (7 oz/yd²). The exterior print pattern is four-color woodland camouflage. The BDU was worn with the Army regular issue leather combat boots. The BDO is a two-layer garment of coat and trousers. The outer fabric shell is a 50/50 nylon/cotton twill, with a durable water-repellent to repel liquid agents. This outer shell is laminated to an inner layer of polyurethane foam liner impregnated with activated carbon. The outer layer pattern is either olive green or four-color woodland camouflage.

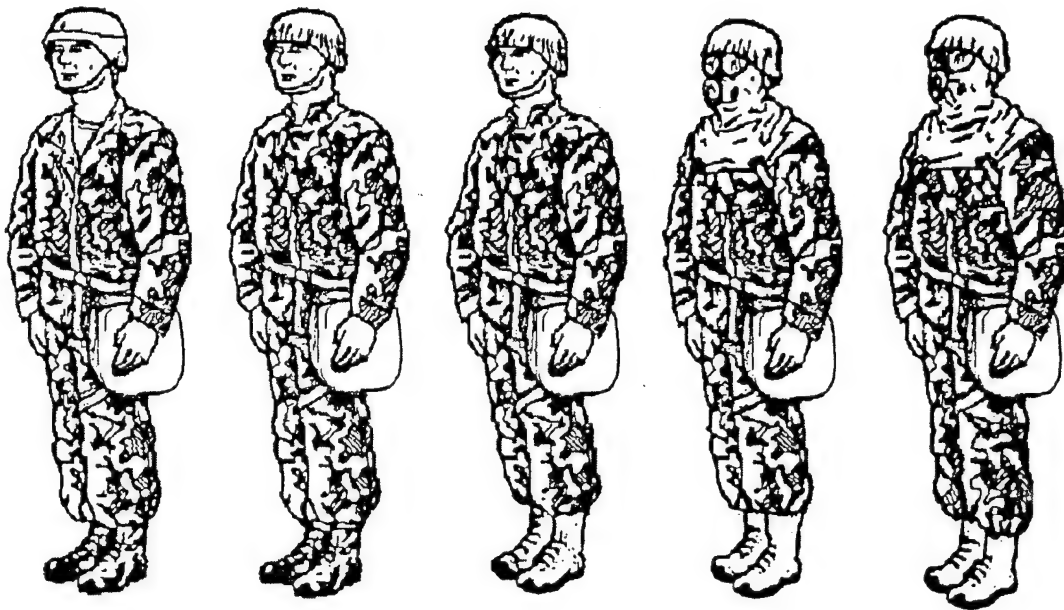
There are a total of five MOPP configurations, described in Table 1 [Field Manual 3-4]. MOPP0 is equivalent to donning only the BDU. MOPP1 to MOPP4 apply to the BDO. All five MOPP configurations were tested. In this study, the BDU was worn over cotton underwear, and the BDO was worn over the BDU. As a baseline condition, a nude (or unclothed) configuration, with the subjects wearing only gym shorts and gym shoes, was also studied.

STUDY DESIGN

The study scenario is described by the following steps.

1. Hydration - 400 ml. water (as a measure to prevent dehydration).
2. Dress and instrumentation.
3. Enter chamber.
4. Decompression of chamber to 4,570 m. condition (approximately 7.5 minutes), for hypobaric sessions.
5. 10 minute resting period while standing on the treadmill.
6. Walking at constant speed of 1.34 m/s (3 mph) on the treadmill for 45 minutes.
7. 10 minute cool-down period while standing on the treadmill.
8. Chamber recompression back to sea level condition (approximately 7.5 minutes), for hypobaric sessions.
9. Exit chamber.
10. Undress.

Table 1 MOPP Configurations (adapted from Field Manual 3-4)



| EQUIPMENT | MOPP CONFIGURATIONS | | | | |
|-------------|---------------------|--------|--------|--------|--------|
| | MOPP 0 | MOPP 1 | MOPP 2 | MOPP 3 | MOPP 4 |
| B D U | Worn | Worn | Worn | Worn | Worn |
| OVERGARMENT | | Worn | Worn | Worn | Worn |
| OVERBOOTS | | | Worn | Worn | Worn |
| MASK/HOOD | | | | Worn | Worn |
| GLOVES | | | | | Worn |

INSTRUMENTATION

The instrumentation phase consisted of attaching probes for measuring skin, clothing, dew point, and rectal temperatures, plus a finger-tip heart rate and blood oxygen monitor.

Temperature Measurements

On the subjects, corresponding temperatures were measured from both inside and outside of the clothing ensemble, at approximately the same location, to determine the parameters across the clothing. Regional skin temperatures (T_{sk}) on the forehead, chest, back, upper arm, lower arm, thigh and lower leg were monitored. At these same sites, regional clothing temperature, T_{cl} , were measured on the outer surface of the clothing ensemble. T_{sk} and T_{cl} were measured using copper-constantan thermocouples. At the chest site, the skin and clothing dew point temperatures were measured with dew point temperature sensors [Graichen et al. 1982] similarly placed on the inside (skin surface) and outside (clothing surface) of the uniform ensemble. For the nude configuration, only a skin dew point sensor was used. The body core (rectal) temperature (T_{re}) was monitored with a 10 cm rectal temperature probe. All temperature data were collected at three-second intervals, using a personal computer system.

Other Measurements

Each subject wore a light-weight oxygen (O_2) mask at all testing sessions. The O_2 flow rate was adjusted such that the subject's blood O_2 content was approximately equivalent to that at a sea level condition. The blood oxygen level was monitored with a stand-alone finger tip blood saturation monitoring system. The monitor also measures the heart rate simultaneously. The heart rate and blood oxygen level were displayed continuously and recorded at 10-minute intervals.

It is expected that in a hypobaric environment, the expiratory heat loss will increase. The O_2 mask reduced excessive expiratory heat loss induced by hypobaria, ensuring a uniform baseline for all subjects in both environments. For the BDO, the M17A1 chemical mask was modified to allow the light-weight oxygen mask to be worn inside the chemical mask.

TREADMILL

The subjects walked on a treadmill with 0° incline. The treadmill was operated at a constant speed of 1.34 m/s (3 mph). The walking exercise was stopped at 45 minutes, or if the human use research criteria limits were reached, or when the subject voluntarily terminated. These last two conditions did not occur during the study.

ANALYSIS

Heat Loss

The dry heat exchange, H_{dry} , for a unit area of clothed skin surface, by the processes of radiation and convection, is [Nishi et al. 1975]

$$H_{dry} = h (\bar{T}_{cl} - T_a) = h \cdot F_{cl} (\bar{T}_{sk} - T_a) \quad W/m^2 \quad \{1\}$$

where, h is the combined convective and radiant transfer coefficient, $h = h_c + h_r$. Burton's thermal efficiency factor, F_{cl} , is a measure of the resistance of clothing to heat flow [Gonzalez and Cena, 1985]. \bar{T}_{sk} , \bar{T}_{cl} , and T_a are skin, clothing surface, and ambient temperature, respectively.

The convective transfer coefficient, h_c , is a function of air velocity and has been shown to be proportional to the barometric pressure, P_b [Gagge and Nishi, 1977].

$$h_c \propto (P_b/760)^{0.55} \quad W/(m^2 \cdot K) \quad \{2\}$$

The evaporative transfer coefficient, h_e , in units of $W/(m^2 \cdot \text{Torr})$, is defined as

$$h_e = LR \cdot h_c = LR \left(\frac{760}{P_b} \right) \cdot h_c \left(\frac{P_b}{760} \right)^{0.55} = 2.2 h_c \left(\frac{760}{P_b} \right)^{0.45} \quad \{3\}$$

where, LR = Lewis relationship = 2.2 K/Torr at sea level [Gagge and Nishi, 1977].

Clothing Insulation

Surface Air Insulation. Surface air insulation is attributable to air held at the clothing surface boundary layer

$$I_a = \frac{(\bar{T}_{cl} - T_a) \cdot f_{cl}}{0.155 \cdot H_{dry}} \quad \text{clo} \quad \{4\}$$

The clothing area factor, f_{cl} , typically increases by $20\% \pm 5\%$ for each clo unit (1 clo = $0.155 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$). For this study, f_{cl} was taken to be 1.2 for BDU and 1.4 for BDO [Breckenridge and Goldman, 1972].

Intrinsic Clothing Insulation. The intrinsic or basic clothing insulation is the insulation from skin to the clothing surface.

$$I_{cl} = \frac{\bar{T}_{sk} - \bar{T}_{cl}}{0.155 \cdot H_{dry}} \quad \text{clo} \quad \{5\}$$

Total clothing insulation. Total clothing insulation is measured from the skin surface to the ambient environment.

$$I_{tot} = \frac{\bar{T}_{sk} - T_a}{0.155 \cdot H_{dry}} \quad \text{clo} \quad \{6\}$$

Evaporative Exchange

Skin Wettedness. Skin wettedness, w , describes the percentage of body skin wetted by sweat [Gonzalez and Cena, 1985].

$$w = (P_{dp} - P_a) / (P_{sk} - P_a) \quad \text{dimensionless} \quad \{7\}$$

where, P_{dp} , P_{sk} , and P_a are water vapor pressure at dew point temperature, T_{sk} , and T_a ,

respectively.

Evaporative Heat Loss. The evaporative (insensible) heat exchange from skin surface is driven by vapor pressure gradient between skin surface and the ambient air. One model of quantifying the evaporative heat transfer, E_{sk} , was proposed by Woodcock [1962].

$$E_{sk} = \frac{(LR \cdot i_m)}{I_{tot}} (P_{sk} - P_a) \quad W/m^2 \quad \{8\}$$

The moisture permeability index, i_m , is a measure of the resistance of clothing to water vapor passage.

STATISTICAL ANALYSIS

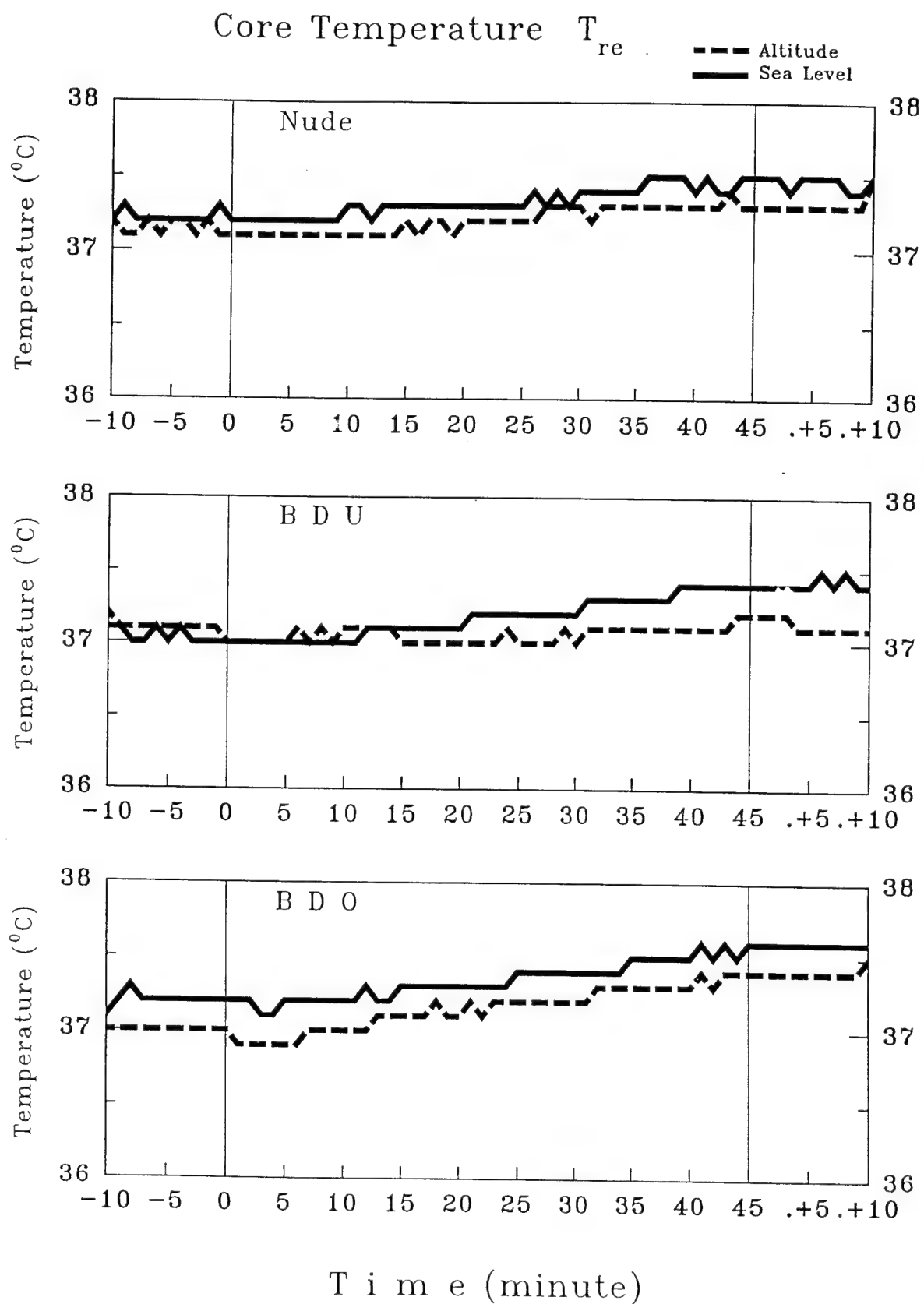
Statistical analysis consisted of repeated measures multiple analysis of variance (MANOVA). Tukey's test (significance level at $\alpha=0.05$) was used as the *post hoc* test for the existence of significant difference between sea level and altitude data, and between clothing configurations. Unless noted otherwise, the differences pointed out in the discussion are statistically significant ($p<0.05$).

RESULTS

The data presented in Figures 1 - 8 are one minute average data points combined from all eight subjects. On the time axis (horizontal axis), negative times (e.g., -10, -5) represent the period prior to the start of treadmill walk. Explicit positive times at the end of walk (e.g., +5, +10) represent rest period after the treadmill exercise. The times at which treadmill walk began and ended are also marked by two vertical time lines.

Figure 1 compares the body core temperatures at sea level and altitude, for clothing configurations Nude, BDU and BDO MOPP 4. The T_{re} shown are the average of the eight subjects. In general, only in BDO MOPP 4 did treadmill walk produce higher

Figure 1



T_{re} (approximately 0.4°C) at the end, when compared to the beginning of exercise. The differences between sea level and altitude were not statistically significant. The T_{re} data indicate that the rate of body core heat storage was not appreciably different between the two environments.

The altitude chamber's environmental temperature was maintained at $21.9 \pm 0.1^{\circ}\text{C}$, at sea level condition, as shown in Figure 2. Figure 2 (top graph) also shows that at the 4,570 m (15,000 ft) environment, the chamber temperature displayed a 20-minute sinusoidal cycle. This 20-minute cycle resulted from the chamber temperature control hunting around the temperature set point, representing an inherent operational limitation of the chamber. The 20-minute cycle artifact has been filtered out with a notch filter and the filtered data are also included in Figure 2 (bottom graph). The sea level temperature is included in both sets of graph of Figure 2 for reference.

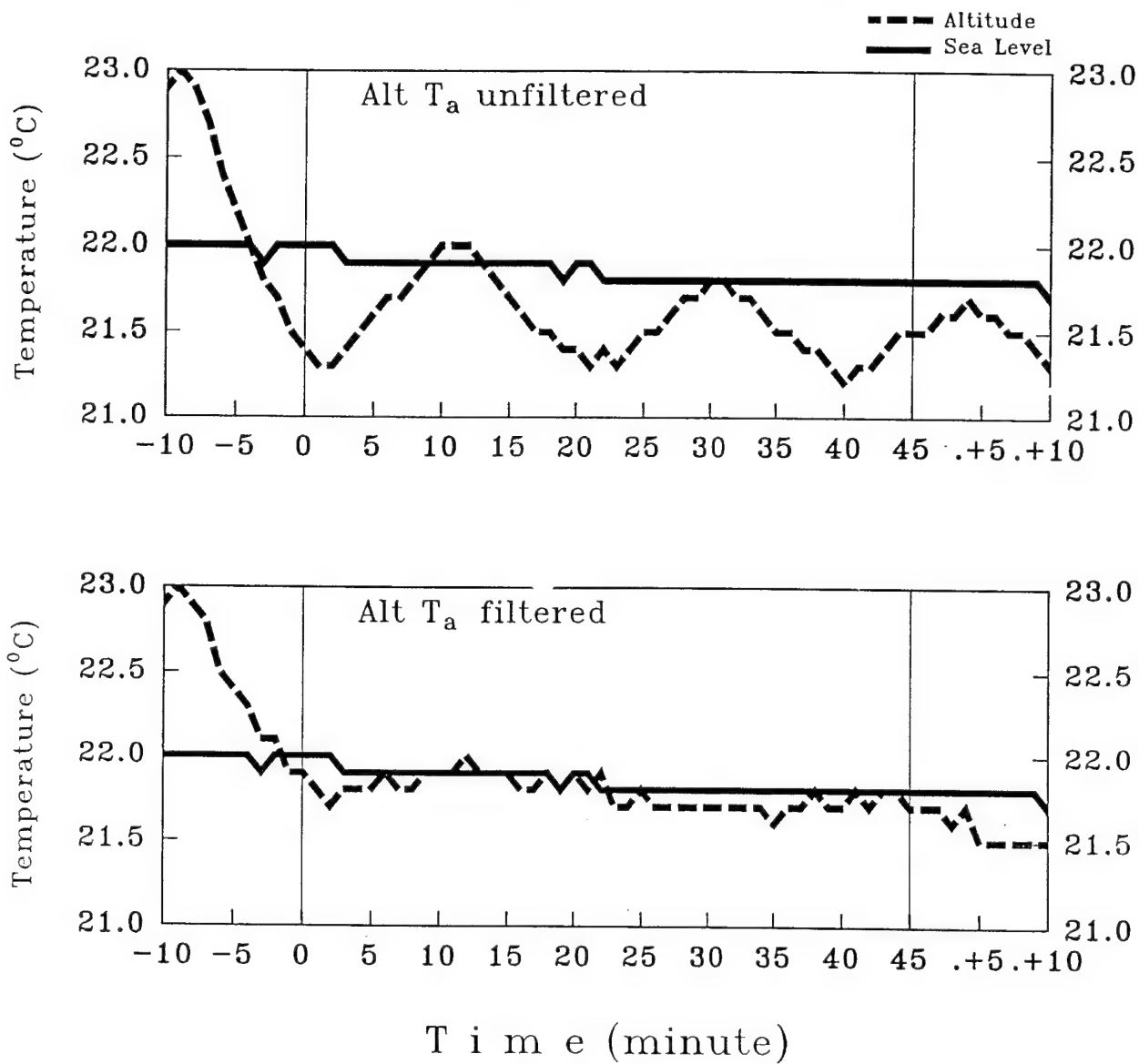
In Figure 2, the initial large decrease in altitude T_a was not an artifact, but the unavoidable result of chamber dynamics. As the chamber barometric pressure decreased when ascending to the altitude environment, air was removed, the remaining air expanded thus releasing heat. The chamber temperature control then slowly cooled the chamber to give the initial decrease in T_a . The chamber temperature control could not be expected to bring down the temperature instantaneously.

The regional skin temperatures were combined to compute a weighed average skin temperature, \bar{T}_{sk} . The weights used were based on the approximate percentage of total body skin surface area of each body segment [Nishi et al. 1975]: head 8%, chest 18%, back 18%, upper arm 8%, lower arm 8%, thigh 20% and lower leg 20%. The same weights were used to compute an average clothing temperature, \bar{T}_{cl} . The 20-minute period notch filter used for the T_a was also applied to \bar{T}_{cl} , which also showed a 20-minute cycle artifact. The \bar{T}_{sk} was not affected by the chamber temperature swings.

The insulation values of I_{cl} and I_{tot} were computed using Equations {5} and {6}. The intrinsic insulation of BDU averaged 0.6 clo, while I_{cl} of the BDO ensembles varied between 0.8 and 1.50 clo. Since the BDO was worn over the BDU, as expected, the I_{cl} of BDO was two to three times higher than the I_{cl} of BDU. The BDO overgarment accounted for most of the insulation. Further donning of the mask, gloves and overboots did not substantially change I_{cl} .

Figure 2

Ambient Temperature T_a



Figures 3, 4, 6, 7, 8 and 9 give the \bar{T}_{sk} , \bar{T}_{cl} , and I_{cl} data for the six clothing configurations: Nude, BDU, MOPP1, MOPP2, MOPP3, and MOPP4, respectively. For the Nude configuration, there were no clothing temperature data, and I_{tot} (equivalent to I_a) was presented. The data used to plot Figures 3, 4, 6, 7, 8 and 9 are also included in the Appendix, as Tables A1 to A6, to allowed for more detailed examination.

The evaporative heat transfer, E_{sk} in Figure 5, was obtained using Equation {8}. The magnitude of the E_{sk} was most probably an overestimation. Because only one dew point sensor was employed in the study, the dew point temperature for the chest region was used to compute w and E_{sk} . Although the chest is the site of high density of sweat glands, the degree of skin wettedness in the chest area may not wholly represent the skin wettedness of other body regions. Also, from the body surface area weights described above, the chest area comprises only 18% of the total body surface area. As Gonzalez & Cena [1985] reported when the local w for the chest region approached saturation (i.e. 100%), the overall body w could be only in the 30% – 60% range. Since w relates directly to E_{sk} , as evident in Equation {9}, the true magnitude of E_{sk} could be only one third as large. The purpose of the E_{sk} data is not for extraction of the exact magnitude of evaporative heat loss, but rather for graphical comparison of the altitude and sea level E_{sk} in continuous time series.

DISCUSSION

Clothing insulation is a function of the dry (nonevaporative) heat loss, H_{dry} , as dictated by Equation {1}. H_{dry} is, in turn, determined by the convective and, to a lesser degree, the radiant heat exchange. In hypobaric environment, the less dense air contains less air molecules to carry heat away from the body. Therefore, at altitude, convection is less efficient in dissipating heat. This can be seen in Equation {2}. The convective coefficient h_c is a function of $(P_b/760)^{0.55}$, hence, h_c decreases with decreasing P_b . Stated in terms of terrestrial elevation, h_c decreases and convective exchange is diminished with increasing elevation. The radiant heat exchange coefficient, h_r , governed by the Stefan-Boltzmann relationship, is not affected by P_b . The h_r averages $5.0 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ [Danielsson, 1990]. On the other hand, the evaporative exchange should increase in the hypobaric environment. The evaporative coefficient is inversely proportional to P_b , varying as a function of $(760/P_b)^{0.45}$, shown in Equation {3}. Hence

as P_b decreases, h_e increases, and the evaporative heat loss is enhanced. While the evaporative transfer does not alter clothing insulation directly, evaporative heat loss does affect skin and clothing temperatures, thus indirectly influences clothing insulation. These heat transfer effects are then modified by clothing itself. Clothing material creates resistance to heat flux. Moreover, clothing configuration, whether loosely worn or tightly wrapped, also affects heat exchange. The complex interactions of these properties affect the final resultant clothing insulation.

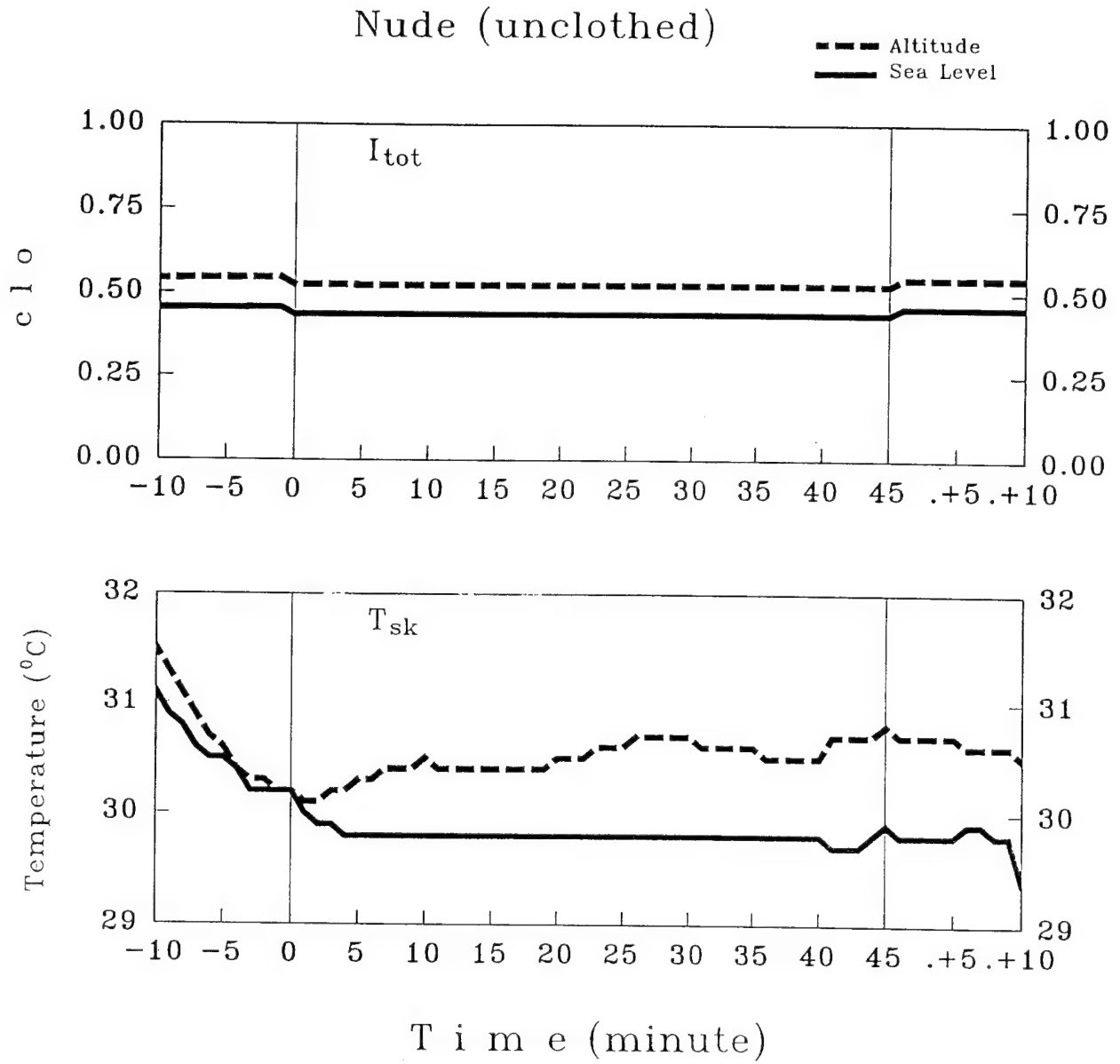
In the following discussion, Δ will be used to denote the difference between the sea level and the altitude environment data.

Nude

The nude configuration served as a baseline condition. In this state, there was zero clothing insulation. The heat exchange between the body and the environment was unhindered by clothing (or minimally hindered by the gym shorts worn). In Figure 3, since there was no clothing, total insulation, I_{tot} , equals exactly the insulation of air layer around the skin surface, I_a . The difference between altitude and sea level $I_{tot} \Delta I_{tot}$ (or equivalently, ΔI_a), was slightly less than 0.1 clo. Insulation was higher at altitude because the less dense air was less effective in dissipating heat. Evaporation had minimal contribution because there was very little sweating in this nude configuration.

The effect of convective heat loss can be seen more readily in the \bar{T}_{sk} . In Figure 3, during the 10-minute pre-walk resting period, convective heat loss lowered \bar{T}_{sk} for both sea level and altitude. After the start of the treadmill walk, sea level \bar{T}_{sk} continued to decline and then leveled off, while the altitude \bar{T}_{sk} increased gradually. At higher altitude, \bar{T}_{sk} increased possibly because of the diminished convective heat loss. These different progressions resulted in an altitude \bar{T}_{sk} that was 1.0°C higher than sea level \bar{T}_{sk} , at the end of the walk. The $\Delta \bar{T}_{sk}$ stayed at approximately 1.0°C during the post-walk rest.

Figure 3



BDU

In Figure 4, I_{cl} did not show significant differences between the two environments. The BDU provided the same insulation at altitude as observed at sea level. At the end of the treadmill walk, in both environments, there was an increase in I_{cl} of approximately 0.2 clo. This was due to the decrease in H_{dry} at the cessation of the walking motion. Both Nielsen et al. [1985] and Lotens & Havenith [1991] reported that walking on a treadmill decreased I_a by 30%-50%, translating to a corresponding decrease in H_{dry} when the walking motion stopped.

Figure 4 also shows that there was a noticeable difference in the clothing temperature $\Delta \bar{T}_{cl}$ but not in skin temperature $\Delta \bar{T}_{sk}$. It appears that heat generated by the body flowed from the skin surface to the outer clothing surface just as easily at altitude as at sea level. Negligible ΔI_{cl} resulted in negligible $\Delta \bar{T}_{sk}$, because resistances to heat flow were similar in both environments. At the outer clothing surface, heat dissipation to the ambient air was however affected by the barometric pressure. At higher altitude, decreased air density reduced the efficiency of convective heat transfer, impeding heat dissipation from outer clothing surface, resulting in higher \bar{T}_{cl} . Furthermore, it is reasonable to assume that the heat content could not be transported back to the skin surface because of unfavorable temperature gradient, i.e. local skin temperature was higher than local clothing temperature. To summarize, negligible ΔI_{cl} resulted in negligible $\Delta \bar{T}_{sk}$, but the effect of barometric pressure difference resulted in a noticeable $\Delta \bar{T}_{cl}$.

Evaporation occurred primarily from the uncovered head and facial region. Presumably, evaporation could also take place through the clothing apertures such as the collar and sleeve openings. The evaporative heat loss, E_{sk} , for BDU in Figure 5, conformed to the theoretical prediction. As expected, E_{sk} was higher at altitude than at sea level. The ΔE_{sk} began to become significant at the 20-minute mark.

The \bar{T}_{sk} and E_{sk} data also suggest that the altitude induced changes in convection and evaporation balanced each other. Because E_{sk} was higher at altitude, and yet $\Delta \bar{T}_{sk}$ was negligible, the logical conclusion must be that the P_b induced decrease in convective transfer and the P_b induced increase in evaporative transfer were approximately equal in magnitude. Thus, the effects canceled out.

Figure 4

B D U

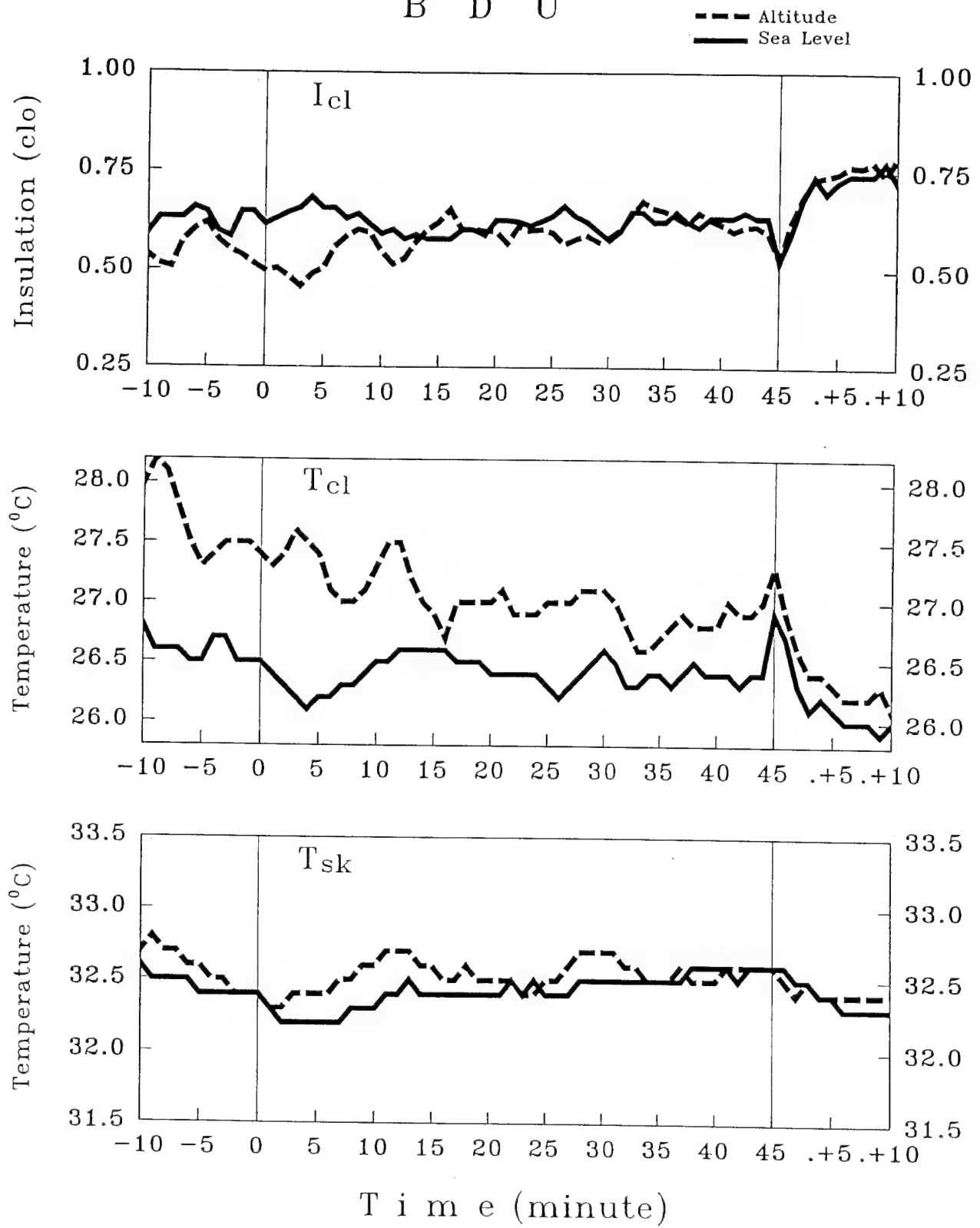
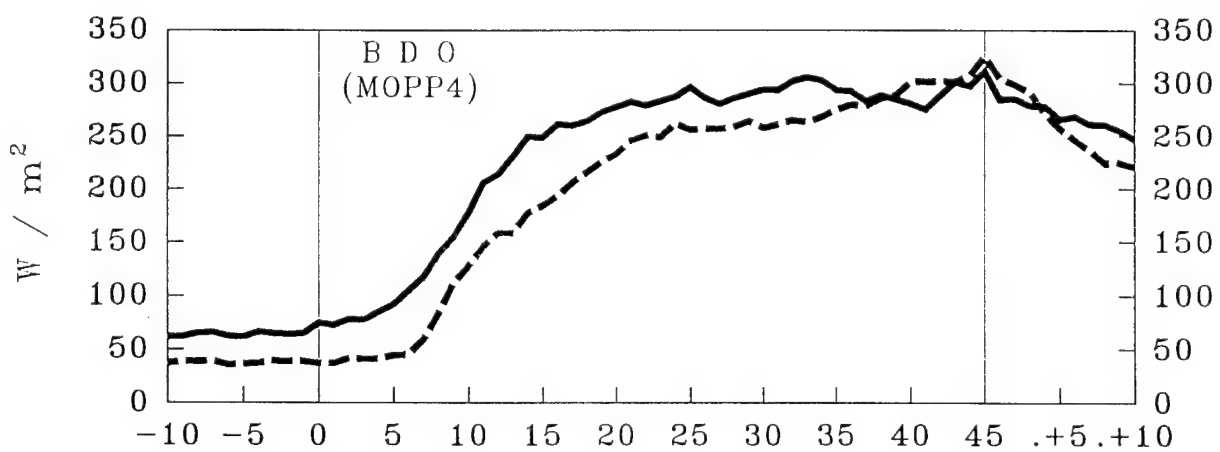
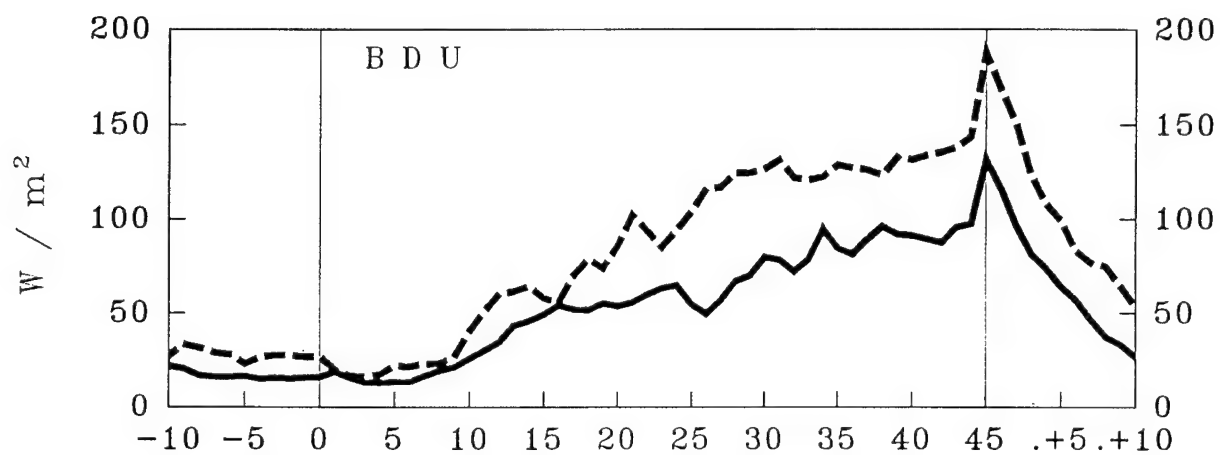


Figure 5

Evaporative Heat Loss (E_{sk})



T i m e (minute)

BDO

As expected, with the donning of the overgarment in MOPP1, I_{cl} increased considerably from that of the BDU. However, the additional donning of the overboots (MOPP2), mask/hood (MOPP3), and gloves (MOPP4) did not further increase the insulation value of the BDO. Havenith et al. [1990] reported a 53% decrease in clothing insulation when walking against wind. In this study, Figures 6–9 show that walking decreased sea level I_{cl} between 30% to 40%. At altitude, the decrease in I_{cl} was comparable. In general, I_{cl} at high altitude was lower than I_{cl} at sea level. The ΔI_{cl} was approximately 0.2 clo.

Across the MOPP configurations, \bar{T}_{cl} were consistently higher at high altitude than at sea level. The data seem to indicate heat retention by the clothing ensemble. The metabolic heat was transported away from the body and stored in the layers of clothing ensemble. The trapped air mass between the multiple clothing layers of the BDO ensemble provided substantial storage capacity. This stored heat could only dissipate by convection to the ambient environment. The low permeability of the BDO, most likely worsened by its water repellent outer finish, impeded the migration of water vapor to the outer clothing surface. Hence, evaporative heat loss could not operate to dissipate the heat stored in the clothing layers. Only convective heat loss could occur. Lower convective heat transfer in the hypobaric environment resulted in the observed higher \bar{T}_{cl} at altitude.

At altitude, \bar{T}_{sk} was lower than at sea level. The data suggested that, as a result of higher diffusivity, the evaporative heat loss from the skin surface was higher at altitude. The fact that the $\Delta \bar{T}_{sk}$ trend was consistent through Figures 6–9, supports a higher evaporative heat loss at high altitude. Unfortunately, the E_{sk} data could not provide additional support, as it did for the BDU case. Under the BDO, the skin surface (chest region) became completely saturated ($w = 100\%$) starting from the 20-minute mark, thus rendered the ΔE_{sk} data (in Figure 5).

\bar{T}_{sk} is also the only parameter for which the MOPP configurations contributed to increasingly larger sea level–altitude difference. For MOPP1 (Figure 6), $\Delta \bar{T}_{sk}$ was negligible. $\Delta \bar{T}_{sk}$ gradually increased through MOPP2 (Figure 7) and MOPP3 (Figure 8). With MOPP4, $\Delta \bar{T}_{sk}$ was as much as 0.8°C higher at sea level than at altitude. With the

donning of the overboots, mask/hood and gloves, evaporative heat loss from the skin surface became increasingly impeded, resulting in the increasingly high \bar{T}_{sk} at each succeeding stage of MOPP.

An interesting effect of the high insulation of the BDO is that it very effectively isolated, thermally, the skin surface from the outer clothing surface. The heat and moisture transfers from the two surfaces, skin and outer clothing, became almost independent. The result was the dominance of either convective or evaporative transfer at these sites. In Figures 6-9, the \bar{T}_{sk} data suggest that at the skin site, evaporative heat transfer dominated. Evaporation transported heat away from the skin surface to the clothing ensemble. The hypobaria induced increase in evaporative heat loss was evident, resulting in a lower \bar{T}_{sk} at altitude. However, the heavy insulation of the BDO prevented sweat vapor from migrating to the outer clothing surface. From the outer clothing surface, heat loss was primarily through convection, evaporation was minimal. Hypobaria induced decrease in convective heat loss at the outer clothing surface resulted in higher \bar{T}_{cl} at altitude. Therefore, clothing insulation elicited a lower \bar{T}_{sk} , but a higher \bar{T}_{cl} at the hypobaric environment, when compared to the results at sea level.

Figure 6

M O P P 1

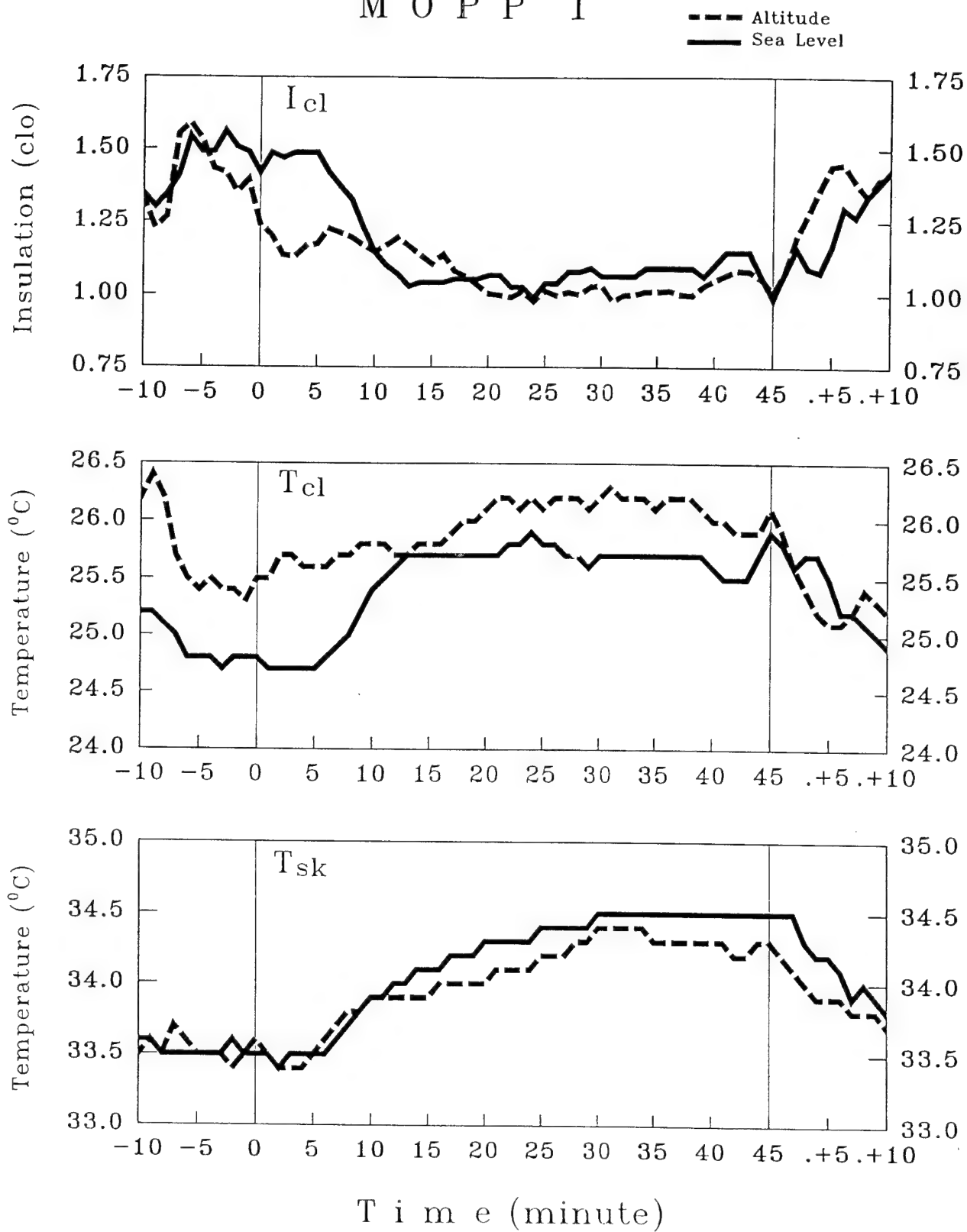


Figure 7

M O P P 2

--- Altitude
— Sea Level

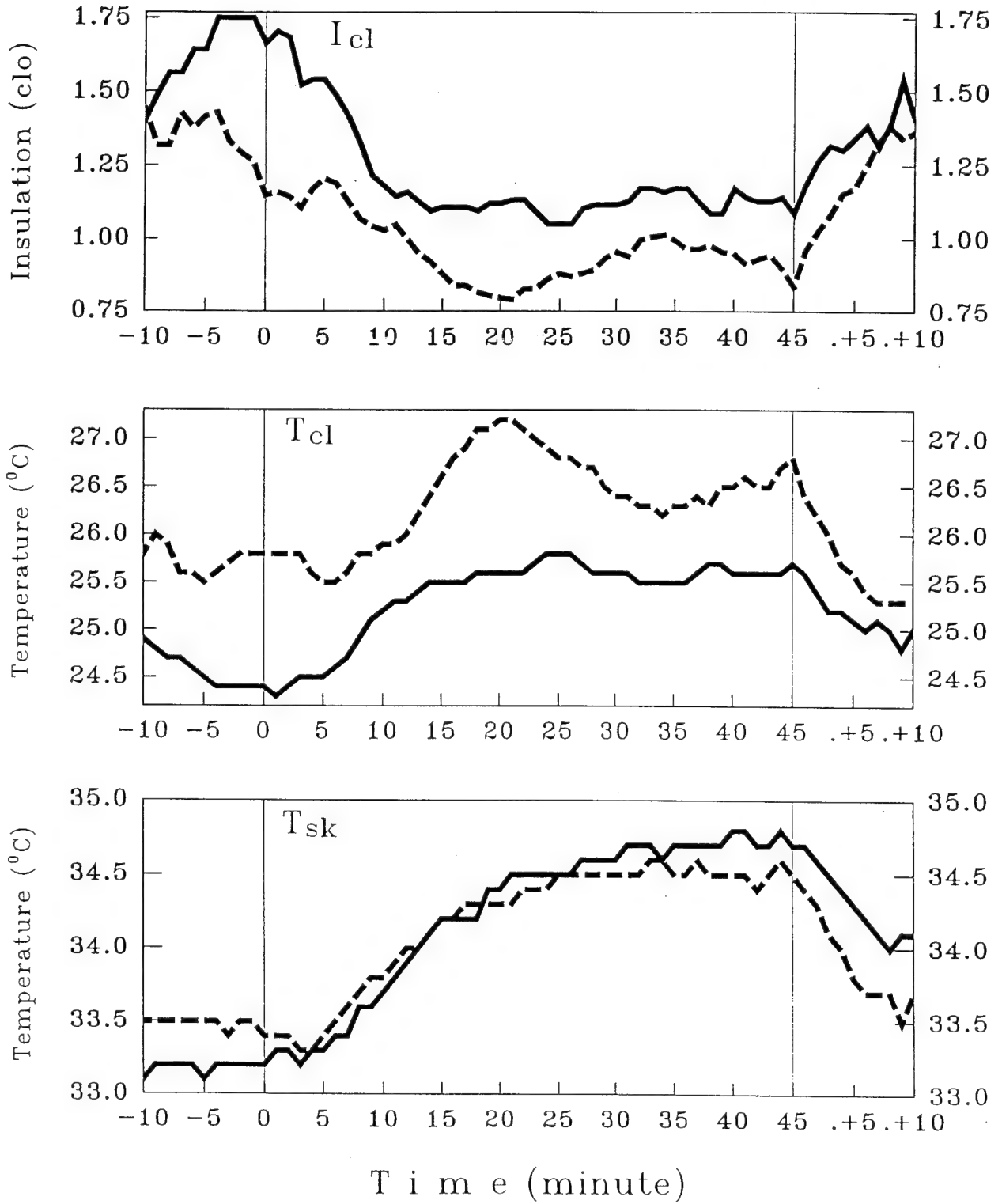


Figure 8

M O P P 3

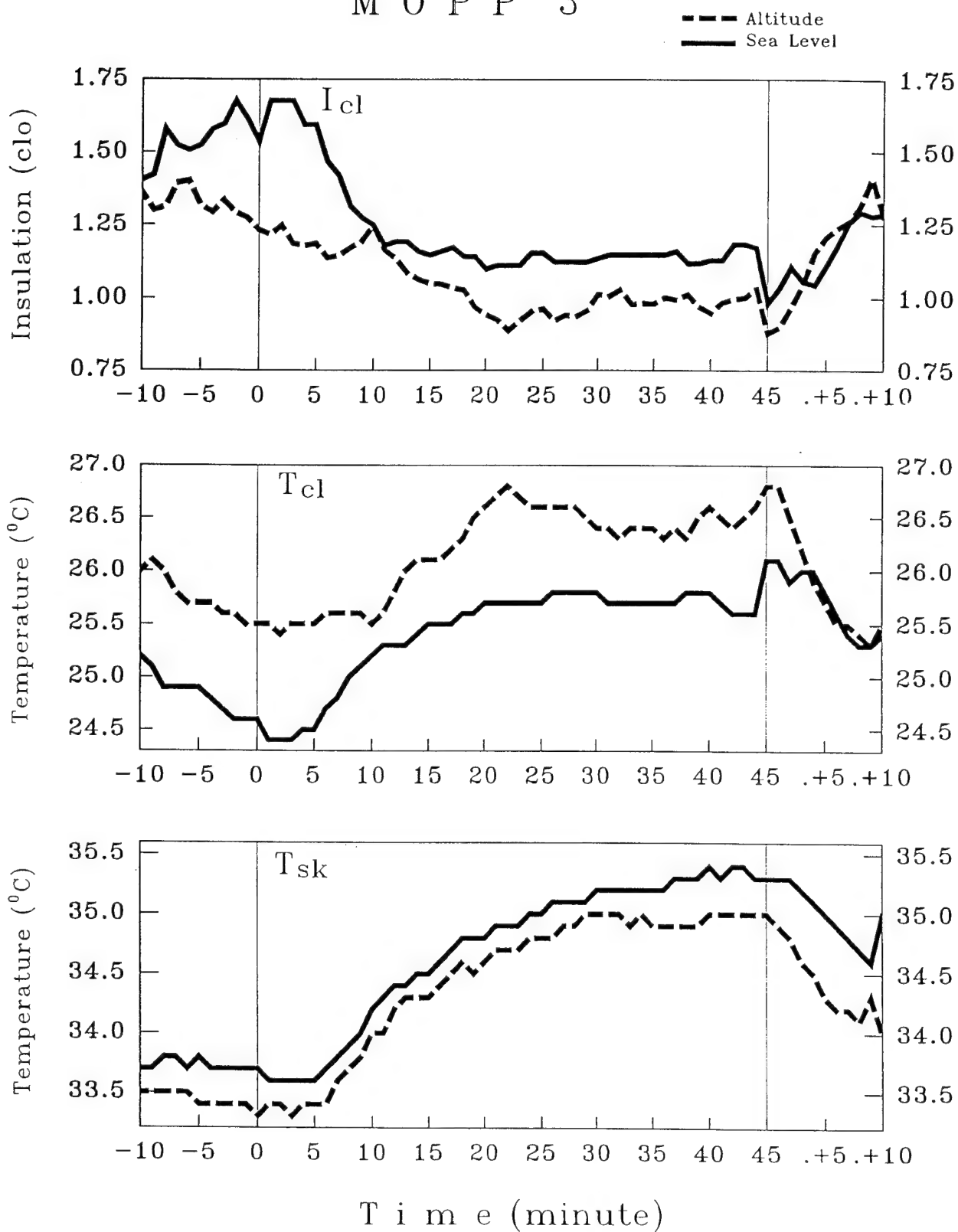
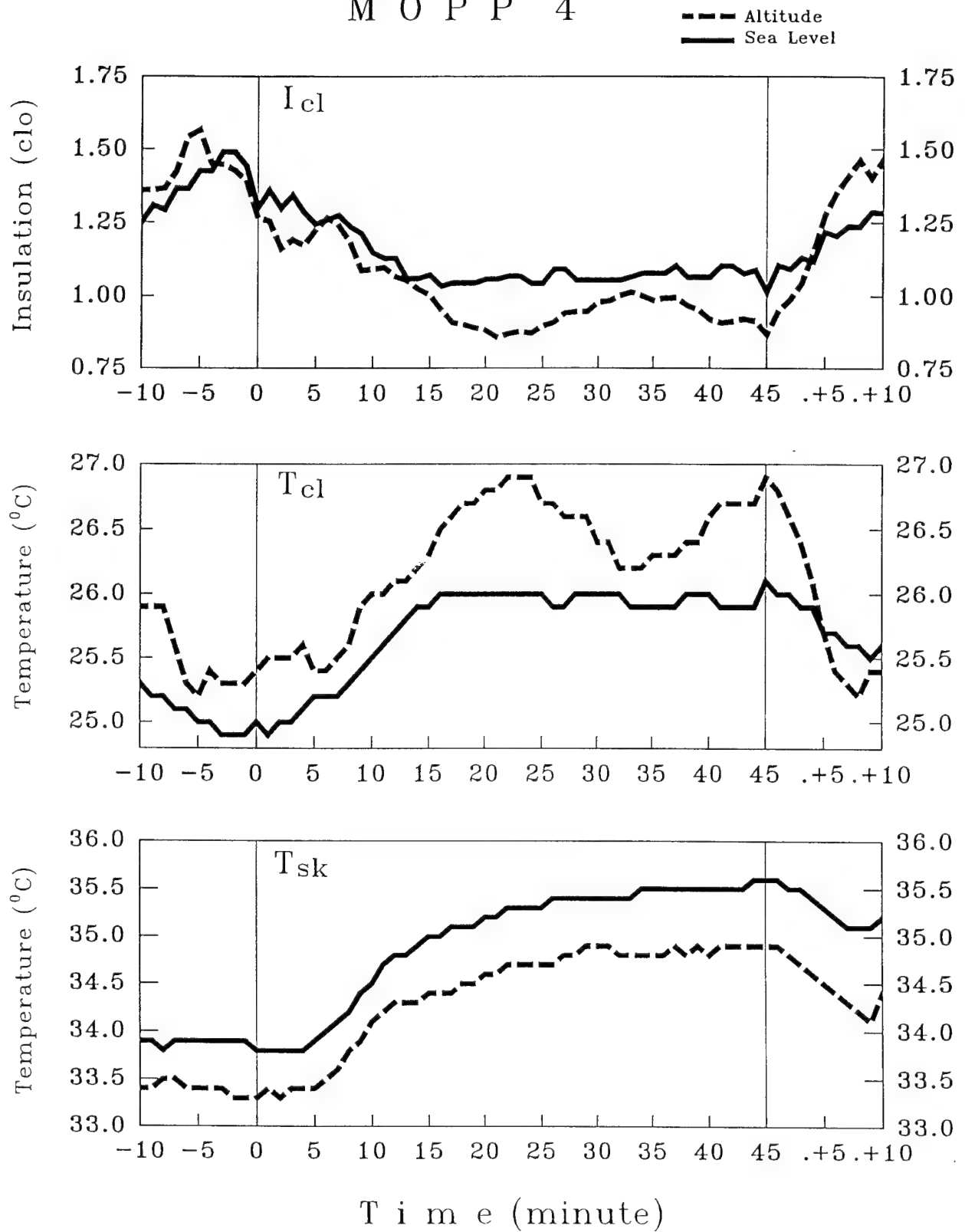


Figure 9

M O P P 4



CONCLUSION

Hypobaria had minimal effects on the intrinsic clothing insulation values. For the less insulative BDU, hypobaria did not affect clothing insulation values. For the more insulative BDO, a maximum difference of 0.2 clo was found between the sea level and altitude environments. We also found that the trapped air mass within clothing layers, not only provided insulation, but also has a large capacity to store metabolic heat.

One interesting effect of high clothing insulation is that it very effectively insulated the skin surface from the outer clothing surface. At one site, the heat transfer mechanisms operated almost independently from the other site. The result was the dominance of either convective or evaporative transfer at these sites. Evaporative transfer dominated at the skin surface. The hypobaria-induced increase in evaporative heat transfer resulted in lower \bar{T}_{sk} at altitude. Heat dissipation from the clothing ensemble to the ambient environment was determined primarily by convection. The heavy BDO insulation prevented moisture from penetrating through the layers of clothing ensemble. At the outer clothing surface, evaporative heat transfer was minimal. The reduced convective heat transfer in the hypobaric environment resulted in higher \bar{T}_{cl} at altitude. Therefore, the combined effects of clothing insulation and hypobaria produced lower \bar{T}_{sk} but higher \bar{T}_{cl} at altitude, when compared to the sea level results.

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APPENDIX

The \bar{T}_{sk} , \bar{T}_{cl} , and I_{cl} data used to plot Figures 3, 4, 6, 7, 8, and 9 (respectively for the six clothing configurations: Nude, BDU, MOPP1, MOPP2, MOPP3, and MOPP4) are presented as Tables A1 to A6, to allowed for subsequent examination.

Table A1 Nude

| minute | Sea Level | | Altitude | |
|--------|-----------|-------|----------|-------|
| | Tsk | I tot | Tsk | I tot |
| -10 | 31.1 | 0.454 | 31.5 | 0.541 |
| -9 | 30.9 | 0.454 | 31.3 | 0.542 |
| -8 | 30.8 | 0.454 | 31.1 | 0.542 |
| -7 | 30.6 | 0.455 | 30.9 | 0.543 |
| -6 | 30.5 | 0.455 | 30.7 | 0.543 |
| -5 | 30.5 | 0.455 | 30.6 | 0.544 |
| -4 | 30.4 | 0.455 | 30.4 | 0.544 |
| -3 | 30.2 | 0.456 | 30.3 | 0.545 |
| -2 | 30.2 | 0.456 | 30.3 | 0.545 |
| -1 | 30.2 | 0.456 | 30.2 | 0.545 |
| 0 | 30.2 | 0.435 | 30.2 | 0.524 |
| 1 | 30.0 | 0.436 | 30.1 | 0.524 |
| 2 | 29.9 | 0.436 | 30.1 | 0.524 |
| 3 | 29.9 | 0.436 | 30.2 | 0.524 |
| 4 | 29.8 | 0.436 | 30.2 | 0.524 |
| 5 | 29.8 | 0.436 | 30.3 | 0.523 |
| 6 | 29.8 | 0.436 | 30.3 | 0.523 |
| 7 | 29.8 | 0.436 | 30.4 | 0.523 |
| 8 | 29.8 | 0.436 | 30.4 | 0.523 |
| 9 | 29.8 | 0.436 | 30.4 | 0.523 |
| 10 | 29.8 | 0.436 | 30.5 | 0.523 |
| 11 | 29.8 | 0.436 | 30.4 | 0.523 |
| 12 | 29.8 | 0.436 | 30.4 | 0.523 |
| 13 | 29.8 | 0.436 | 30.4 | 0.523 |
| 14 | 29.8 | 0.436 | 30.4 | 0.523 |
| 15 | 29.8 | 0.436 | 30.4 | 0.523 |
| 16 | 29.8 | 0.436 | 30.4 | 0.523 |
| 17 | 29.8 | 0.436 | 30.4 | 0.523 |
| 18 | 29.8 | 0.436 | 30.4 | 0.523 |
| 19 | 29.8 | 0.436 | 30.4 | 0.523 |
| 20 | 29.8 | 0.436 | 30.5 | 0.523 |
| 21 | 29.8 | 0.436 | 30.5 | 0.523 |
| 22 | 29.8 | 0.436 | 30.5 | 0.523 |
| 23 | 29.8 | 0.436 | 30.6 | 0.522 |
| 24 | 29.8 | 0.436 | 30.6 | 0.522 |
| 25 | 29.8 | 0.436 | 30.6 | 0.522 |
| 26 | 29.8 | 0.436 | 30.7 | 0.522 |
| 27 | 29.8 | 0.436 | 30.7 | 0.522 |
| 28 | 29.8 | 0.436 | 30.7 | 0.522 |
| 29 | 29.8 | 0.436 | 30.7 | 0.522 |
| 30 | 29.8 | 0.436 | 30.7 | 0.522 |

Table A1 Nude (continued)

| minute | Sea Level | | Altitude | |
|--------|-----------|-------|----------|-------|
| | Tsk | I tot | Tsk | I tot |
| 31 | 29.8 | 0.436 | 30.6 | 0.522 |
| 32 | 29.8 | 0.436 | 30.6 | 0.522 |
| 33 | 29.8 | 0.436 | 30.6 | 0.522 |
| 34 | 29.8 | 0.436 | 30.6 | 0.522 |
| 35 | 29.8 | 0.436 | 30.6 | 0.522 |
| 36 | 29.8 | 0.436 | 30.5 | 0.523 |
| 37 | 29.8 | 0.436 | 30.5 | 0.523 |
| 38 | 29.8 | 0.436 | 30.5 | 0.523 |
| 39 | 29.8 | 0.436 | 30.5 | 0.523 |
| 40 | 29.8 | 0.436 | 30.5 | 0.523 |
| 41 | 29.7 | 0.436 | 30.7 | 0.522 |
| 42 | 29.7 | 0.436 | 30.7 | 0.522 |
| 43 | 29.7 | 0.436 | 30.7 | 0.522 |
| 44 | 29.8 | 0.436 | 30.7 | 0.522 |
| 45 | 29.9 | 0.436 | 30.8 | 0.522 |
| +1 | 29.8 | 0.456 | 30.7 | 0.543 |
| +2 | 29.8 | 0.456 | 30.7 | 0.543 |
| +3 | 29.8 | 0.456 | 30.7 | 0.543 |
| +4 | 29.8 | 0.456 | 30.7 | 0.543 |
| +5 | 29.8 | 0.456 | 30.7 | 0.543 |
| +6 | 29.9 | 0.456 | 30.6 | 0.544 |
| +7 | 29.9 | 0.456 | 30.6 | 0.544 |
| +8 | 29.8 | 0.456 | 30.6 | 0.544 |
| +9 | 29.8 | 0.456 | 30.6 | 0.544 |
| +10 | 29.4 | 0.457 | 30.5 | 0.544 |

Table A2 B D U

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| -10 | 32.6 | 26.8 | 0.595 | 32.7 | 28.0 | 0.537 |
| -9 | 32.5 | 26.6 | 0.632 | 32.8 | 28.2 | 0.515 |
| -8 | 32.5 | 26.6 | 0.632 | 32.7 | 28.1 | 0.507 |
| -7 | 32.5 | 26.6 | 0.632 | 32.7 | 27.8 | 0.574 |
| -6 | 32.5 | 26.5 | 0.658 | 32.6 | 27.5 | 0.603 |
| -5 | 32.4 | 26.5 | 0.647 | 32.6 | 27.3 | 0.620 |
| -4 | 32.4 | 26.7 | 0.598 | 32.5 | 27.4 | 0.576 |
| -3 | 32.4 | 26.7 | 0.585 | 32.5 | 27.5 | 0.551 |
| -2 | 32.4 | 26.5 | 0.647 | 32.4 | 27.5 | 0.537 |
| -1 | 32.4 | 26.5 | 0.647 | 32.4 | 27.5 | 0.516 |
| 0 | 32.4 | 26.5 | 0.616 | 32.4 | 27.4 | 0.498 |
| 1 | 32.3 | 26.4 | 0.630 | 32.3 | 27.3 | 0.504 |
| 2 | 32.2 | 26.3 | 0.645 | 32.3 | 27.4 | 0.483 |
| 3 | 32.2 | 26.2 | 0.656 | 32.4 | 27.6 | 0.458 |
| 4 | 32.2 | 26.1 | 0.683 | 32.4 | 27.5 | 0.489 |
| 5 | 32.2 | 26.2 | 0.656 | 32.4 | 27.4 | 0.504 |
| 6 | 32.2 | 26.2 | 0.656 | 32.4 | 27.1 | 0.559 |
| 7 | 32.2 | 26.3 | 0.630 | 32.5 | 27.0 | 0.585 |
| 8 | 32.3 | 26.3 | 0.641 | 32.5 | 27.0 | 0.602 |
| 9 | 32.3 | 26.4 | 0.616 | 32.6 | 27.1 | 0.595 |
| 10 | 32.3 | 26.5 | 0.592 | 32.6 | 27.3 | 0.547 |
| 11 | 32.4 | 26.5 | 0.602 | 32.7 | 27.5 | 0.515 |
| 12 | 32.4 | 26.6 | 0.579 | 32.7 | 27.5 | 0.529 |
| 13 | 32.5 | 26.6 | 0.589 | 32.7 | 27.2 | 0.571 |
| 14 | 32.4 | 26.6 | 0.579 | 32.6 | 27.0 | 0.602 |
| 15 | 32.4 | 26.6 | 0.579 | 32.6 | 26.9 | 0.621 |
| 16 | 32.4 | 26.6 | 0.579 | 32.5 | 26.7 | 0.653 |
| 17 | 32.4 | 26.5 | 0.602 | 32.5 | 27.0 | 0.603 |
| 18 | 32.4 | 26.5 | 0.602 | 32.6 | 27.0 | 0.604 |
| 19 | 32.4 | 26.5 | 0.589 | 32.5 | 27.0 | 0.599 |
| 20 | 32.4 | 26.4 | 0.626 | 32.5 | 27.0 | 0.598 |
| 21 | 32.4 | 26.4 | 0.626 | 32.5 | 27.1 | 0.568 |
| 22 | 32.5 | 26.4 | 0.623 | 32.5 | 26.9 | 0.611 |
| 23 | 32.4 | 26.4 | 0.613 | 32.4 | 26.9 | 0.600 |
| 24 | 32.5 | 26.4 | 0.623 | 32.4 | 26.9 | 0.603 |
| 25 | 32.4 | 26.3 | 0.637 | 32.5 | 27.0 | 0.595 |
| 26 | 32.4 | 26.2 | 0.662 | 32.5 | 27.0 | 0.566 |
| 27 | 32.4 | 26.3 | 0.637 | 32.6 | 27.0 | 0.579 |
| 28 | 32.5 | 26.4 | 0.623 | 32.7 | 27.1 | 0.588 |
| 29 | 32.5 | 26.5 | 0.599 | 32.7 | 27.1 | 0.573 |
| 30 | 32.5 | 26.6 | 0.577 | 32.7 | 27.1 | 0.585 |

Table A2 B D U (continued)

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| 31 | 32.5 | 26.5 | 0.599 | 32.7 | 27.0 | 0.603 |
| 32 | 32.5 | 26.3 | 0.647 | 32.6 | 26.8 | 0.640 |
| 33 | 32.5 | 26.3 | 0.647 | 32.6 | 26.6 | 0.674 |
| 34 | 32.5 | 26.4 | 0.623 | 32.5 | 26.6 | 0.657 |
| 35 | 32.5 | 26.4 | 0.623 | 32.5 | 26.7 | 0.650 |
| 36 | 32.5 | 26.3 | 0.647 | 32.5 | 26.8 | 0.634 |
| 37 | 32.5 | 26.4 | 0.623 | 32.6 | 26.9 | 0.619 |
| 38 | 32.6 | 26.5 | 0.609 | 32.5 | 26.8 | 0.646 |
| 39 | 32.6 | 26.4 | 0.633 | 32.5 | 26.8 | 0.628 |
| 40 | 32.6 | 26.4 | 0.633 | 32.5 | 26.8 | 0.616 |
| 41 | 32.6 | 26.4 | 0.633 | 32.6 | 27.0 | 0.599 |
| 42 | 32.5 | 26.3 | 0.647 | 32.6 | 26.9 | 0.610 |
| 43 | 32.6 | 26.4 | 0.633 | 32.6 | 26.9 | 0.613 |
| 44 | 32.6 | 26.4 | 0.633 | 32.6 | 27.0 | 0.596 |
| 45 | 32.6 | 26.9 | 0.524 | 32.6 | 27.3 | 0.528 |
| +1 | 32.6 | 26.7 | 0.593 | 32.5 | 26.9 | 0.622 |
| +2 | 32.5 | 26.3 | 0.680 | 32.4 | 26.6 | 0.686 |
| +3 | 32.5 | 26.1 | 0.735 | 32.5 | 26.4 | 0.732 |
| +4 | 32.4 | 26.2 | 0.696 | 32.4 | 26.4 | 0.738 |
| +5 | 32.4 | 26.1 | 0.724 | 32.4 | 26.3 | 0.746 |
| +6 | 32.3 | 26.0 | 0.741 | 32.4 | 26.2 | 0.764 |
| +7 | 32.3 | 26.0 | 0.741 | 32.4 | 26.2 | 0.762 |
| +8 | 32.3 | 26.0 | 0.741 | 32.4 | 26.2 | 0.773 |
| +9 | 32.3 | 25.9 | 0.772 | 32.4 | 26.3 | 0.738 |
| +10 | 32.3 | 26.0 | 0.724 | 32.4 | 26.1 | 0.790 |

Table A3 M O P P 1

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| -10 | 33.6 | 25.2 | 1.343 | 33.5 | 26.2 | 1.323 |
| -9 | 33.6 | 25.2 | 1.301 | 33.6 | 26.4 | 1.228 |
| -8 | 33.5 | 25.1 | 1.344 | 33.5 | 26.2 | 1.266 |
| -7 | 33.5 | 25.0 | 1.406 | 33.7 | 25.7 | 1.552 |
| -6 | 33.5 | 24.8 | 1.543 | 33.6 | 25.5 | 1.589 |
| -5 | 33.5 | 24.8 | 1.490 | 33.5 | 25.4 | 1.531 |
| -4 | 33.5 | 24.8 | 1.490 | 33.5 | 25.5 | 1.431 |
| -3 | 33.5 | 24.7 | 1.561 | 33.5 | 25.4 | 1.418 |
| -2 | 33.6 | 24.8 | 1.507 | 33.4 | 25.4 | 1.352 |
| -1 | 33.5 | 24.8 | 1.490 | 33.5 | 25.3 | 1.392 |
| 0 | 33.5 | 24.8 | 1.418 | 33.6 | 25.5 | 1.243 |
| 1 | 33.5 | 24.7 | 1.486 | 33.5 | 25.5 | 1.204 |
| 2 | 33.4 | 24.7 | 1.469 | 33.4 | 25.7 | 1.136 |
| 3 | 33.5 | 24.7 | 1.486 | 33.4 | 25.7 | 1.129 |
| 4 | 33.5 | 24.7 | 1.486 | 33.4 | 25.6 | 1.165 |
| 5 | 33.5 | 24.7 | 1.486 | 33.5 | 25.6 | 1.173 |
| 6 | 33.5 | 24.8 | 1.418 | 33.6 | 25.6 | 1.226 |
| 7 | 33.6 | 24.9 | 1.370 | 33.7 | 25.7 | 1.212 |
| 8 | 33.7 | 25.0 | 1.325 | 33.8 | 25.7 | 1.195 |
| 9 | 33.8 | 25.2 | 1.230 | 33.8 | 25.8 | 1.169 |
| 10 | 33.9 | 25.4 | 1.145 | 33.9 | 25.8 | 1.145 |
| 11 | 33.9 | 25.5 | 1.100 | 33.9 | 25.8 | 1.169 |
| 12 | 34.0 | 25.6 | 1.070 | 33.9 | 25.7 | 1.195 |
| 13 | 34.0 | 25.7 | 1.029 | 33.9 | 25.7 | 1.166 |
| 14 | 34.1 | 25.7 | 1.041 | 33.9 | 25.8 | 1.135 |
| 15 | 34.1 | 25.7 | 1.041 | 33.9 | 25.8 | 1.106 |
| 16 | 34.1 | 25.7 | 1.041 | 34.0 | 25.8 | 1.137 |
| 17 | 34.2 | 25.7 | 1.053 | 34.0 | 25.9 | 1.080 |
| 18 | 34.2 | 25.7 | 1.053 | 34.0 | 26.0 | 1.062 |
| 19 | 34.2 | 25.7 | 1.053 | 34.0 | 26.0 | 1.032 |
| 20 | 34.3 | 25.7 | 1.066 | 34.0 | 26.1 | 1.003 |
| 21 | 34.3 | 25.7 | 1.066 | 34.1 | 26.2 | 0.998 |
| 22 | 34.3 | 25.8 | 1.026 | 34.1 | 26.2 | 0.990 |
| 23 | 34.3 | 25.8 | 1.026 | 34.1 | 26.1 | 1.011 |
| 24 | 34.3 | 25.9 | 0.988 | 34.1 | 26.2 | 0.977 |
| 25 | 34.4 | 25.8 | 1.038 | 34.2 | 26.1 | 1.013 |
| 26 | 34.4 | 25.8 | 1.038 | 34.2 | 26.2 | 0.996 |
| 27 | 34.4 | 25.7 | 1.078 | 34.2 | 26.2 | 1.008 |
| 28 | 34.4 | 25.7 | 1.078 | 34.3 | 26.2 | 1.000 |
| 29 | 34.4 | 25.6 | 1.091 | 34.3 | 26.1 | 1.027 |
| 30 | 34.5 | 25.7 | 1.063 | 34.4 | 26.2 | 1.030 |

Table A3 M O P P 1 (continued)

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| 31 | 34.5 | 25.7 | 1.063 | 34.4 | 26.3 | 0.977 |
| 32 | 34.5 | 25.7 | 1.063 | 34.4 | 26.2 | 0.998 |
| 33 | 34.5 | 25.7 | 1.063 | 34.4 | 26.2 | 1.000 |
| 34 | 34.5 | 25.7 | 1.091 | 34.4 | 26.2 | 1.011 |
| 35 | 34.5 | 25.7 | 1.091 | 34.3 | 26.1 | 1.010 |
| 36 | 34.5 | 25.7 | 1.091 | 34.3 | 26.2 | 1.014 |
| 37 | 34.5 | 25.7 | 1.091 | 34.3 | 26.2 | 1.001 |
| 38 | 34.5 | 25.7 | 1.091 | 34.3 | 26.2 | 0.998 |
| 39 | 34.5 | 25.7 | 1.063 | 34.3 | 26.1 | 1.030 |
| 40 | 34.5 | 25.6 | 1.103 | 34.3 | 26.0 | 1.050 |
| 41 | 34.5 | 25.5 | 1.146 | 34.3 | 26.0 | 1.068 |
| 42 | 34.5 | 25.5 | 1.146 | 34.2 | 25.9 | 1.084 |
| 43 | 34.5 | 25.5 | 1.146 | 34.2 | 25.9 | 1.081 |
| 44 | 34.5 | 25.7 | 1.063 | 34.3 | 25.9 | 1.056 |
| 45 | 34.5 | 25.9 | 0.987 | 34.3 | 26.1 | 1.009 |
| +1 | 34.5 | 25.8 | 1.076 | 34.2 | 25.9 | 1.075 |
| +2 | 34.5 | 25.6 | 1.159 | 34.1 | 25.6 | 1.198 |
| +3 | 34.3 | 25.7 | 1.091 | 34.0 | 25.4 | 1.278 |
| +4 | 34.2 | 25.7 | 1.078 | 33.9 | 25.2 | 1.365 |
| +5 | 34.2 | 25.5 | 1.164 | 33.9 | 25.1 | 1.442 |
| +6 | 34.1 | 25.2 | 1.298 | 33.9 | 25.1 | 1.448 |
| +7 | 33.9 | 25.2 | 1.268 | 33.8 | 25.2 | 1.387 |
| +8 | 34.0 | 25.1 | 1.337 | 33.8 | 25.4 | 1.338 |
| +9 | 33.9 | 25.0 | 1.380 | 33.8 | 25.3 | 1.395 |
| +10 | 33.8 | 24.9 | 1.425 | 33.7 | 25.2 | 1.402 |

Table A4 M O P P 2

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| -10 | 33.1 | 24.9 | 1.404 | 33.5 | 25.8 | 1.440 |
| -9 | 33.2 | 24.8 | 1.490 | 33.5 | 26.0 | 1.318 |
| -8 | 33.2 | 24.7 | 1.564 | 33.5 | 25.9 | 1.319 |
| -7 | 33.2 | 24.7 | 1.564 | 33.5 | 25.6 | 1.427 |
| -6 | 33.2 | 24.6 | 1.644 | 33.5 | 25.6 | 1.377 |
| -5 | 33.1 | 24.5 | 1.644 | 33.5 | 25.5 | 1.416 |
| -4 | 33.2 | 24.4 | 1.751 | 33.5 | 25.6 | 1.429 |
| -3 | 33.2 | 24.4 | 1.751 | 33.4 | 25.7 | 1.331 |
| -2 | 33.2 | 24.4 | 1.751 | 33.5 | 25.8 | 1.293 |
| -1 | 33.2 | 24.4 | 1.751 | 33.5 | 25.8 | 1.265 |
| 0 | 33.2 | 24.4 | 1.666 | 33.4 | 25.8 | 1.149 |
| 1 | 33.3 | 24.3 | 1.704 | 33.4 | 25.8 | 1.159 |
| 2 | 33.3 | 24.4 | 1.685 | 33.4 | 25.8 | 1.145 |
| 3 | 33.2 | 24.5 | 1.524 | 33.3 | 25.8 | 1.106 |
| 4 | 33.3 | 24.5 | 1.542 | 33.3 | 25.6 | 1.170 |
| 5 | 33.3 | 24.5 | 1.542 | 33.4 | 25.5 | 1.205 |
| 6 | 33.4 | 24.6 | 1.486 | 33.5 | 25.5 | 1.189 |
| 7 | 33.4 | 24.7 | 1.418 | 33.6 | 25.6 | 1.128 |
| 8 | 33.6 | 24.9 | 1.326 | 33.7 | 25.8 | 1.068 |
| 9 | 33.6 | 25.1 | 1.216 | 33.8 | 25.8 | 1.042 |
| 10 | 33.7 | 25.2 | 1.180 | 33.8 | 25.9 | 1.028 |
| 11 | 33.8 | 25.3 | 1.145 | 33.9 | 25.9 | 1.046 |
| 12 | 33.9 | 25.3 | 1.159 | 34.0 | 26.0 | 0.998 |
| 13 | 34.0 | 25.4 | 1.126 | 34.0 | 26.2 | 0.948 |
| 14 | 34.1 | 25.5 | 1.095 | 34.1 | 26.4 | 0.920 |
| 15 | 34.2 | 25.5 | 1.108 | 34.2 | 26.6 | 0.878 |
| 16 | 34.2 | 25.5 | 1.108 | 34.2 | 26.8 | 0.837 |
| 17 | 34.2 | 25.5 | 1.108 | 34.3 | 26.9 | 0.837 |
| 18 | 34.2 | 25.6 | 1.095 | 34.3 | 27.1 | 0.814 |
| 19 | 34.4 | 25.6 | 1.121 | 34.3 | 27.1 | 0.803 |
| 20 | 34.4 | 25.6 | 1.121 | 34.3 | 27.2 | 0.795 |
| 21 | 34.5 | 25.6 | 1.133 | 34.3 | 27.2 | 0.790 |
| 22 | 34.5 | 25.6 | 1.133 | 34.4 | 27.1 | 0.826 |
| 23 | 34.5 | 25.7 | 1.091 | 34.4 | 27.0 | 0.827 |
| 24 | 34.5 | 25.8 | 1.050 | 34.4 | 26.9 | 0.860 |
| 25 | 34.5 | 25.8 | 1.050 | 34.5 | 26.8 | 0.878 |
| 26 | 34.5 | 25.8 | 1.050 | 34.5 | 26.8 | 0.869 |
| 27 | 34.6 | 25.7 | 1.103 | 34.5 | 26.7 | 0.880 |
| 28 | 34.6 | 25.6 | 1.116 | 34.5 | 26.7 | 0.891 |
| 29 | 34.6 | 25.6 | 1.116 | 34.5 | 26.5 | 0.932 |
| 30 | 34.6 | 25.6 | 1.116 | 34.5 | 26.4 | 0.952 |

Table A4 M O P P 2 (continued)

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| 31 | 34.7 | 25.6 | 1.128 | 34.5 | 26.4 | 0.937 |
| 32 | 34.7 | 25.5 | 1.172 | 34.5 | 26.3 | 0.994 |
| 33 | 34.7 | 25.5 | 1.172 | 34.6 | 26.3 | 1.005 |
| 34 | 34.6 | 25.5 | 1.159 | 34.6 | 26.2 | 1.012 |
| 35 | 34.7 | 25.5 | 1.172 | 34.5 | 26.3 | 0.993 |
| 36 | 34.7 | 25.5 | 1.172 | 34.5 | 26.3 | 0.963 |
| 37 | 34.7 | 25.6 | 1.128 | 34.6 | 26.4 | 0.964 |
| 38 | 34.7 | 25.7 | 1.087 | 34.5 | 26.3 | 0.976 |
| 39 | 34.7 | 25.7 | 1.087 | 34.5 | 26.5 | 0.954 |
| 40 | 34.8 | 25.6 | 1.171 | 34.5 | 26.5 | 0.947 |
| 41 | 34.8 | 25.6 | 1.141 | 34.5 | 26.6 | 0.911 |
| 42 | 34.7 | 25.6 | 1.128 | 34.4 | 26.5 | 0.930 |
| 43 | 34.7 | 25.6 | 1.128 | 34.5 | 26.5 | 0.942 |
| 44 | 34.8 | 25.6 | 1.141 | 34.6 | 26.7 | 0.896 |
| 45 | 34.7 | 25.7 | 1.087 | 34.5 | 26.8 | 0.835 |
| +1 | 34.7 | 25.6 | 1.185 | 34.4 | 26.4 | 0.960 |
| +2 | 34.6 | 25.4 | 1.266 | 34.3 | 26.2 | 1.025 |
| +3 | 34.5 | 25.2 | 1.317 | 34.1 | 26.0 | 1.081 |
| +4 | 34.4 | 25.2 | 1.303 | 34.0 | 25.7 | 1.154 |
| +5 | 34.3 | 25.1 | 1.342 | 33.8 | 25.6 | 1.173 |
| +6 | 34.2 | 25.0 | 1.383 | 33.7 | 25.4 | 1.251 |
| +7 | 34.1 | 25.1 | 1.313 | 33.7 | 25.3 | 1.332 |
| +8 | 34.0 | 25.0 | 1.395 | 33.7 | 25.3 | 1.380 |
| +9 | 34.1 | 24.8 | 1.539 | 33.5 | 25.3 | 1.340 |
| +10 | 34.1 | 25.0 | 1.411 | 33.7 | 25.3 | 1.364 |

Table A5 M O P P 3

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| -10 | 33.7 | 25.2 | 1.405 | 33.5 | 26.0 | 1.359 |
| -9 | 33.7 | 25.1 | 1.422 | 33.5 | 26.1 | 1.300 |
| -8 | 33.8 | 24.9 | 1.578 | 33.5 | 26.0 | 1.313 |
| -7 | 33.8 | 24.9 | 1.523 | 33.5 | 25.8 | 1.393 |
| -6 | 33.7 | 24.9 | 1.506 | 33.5 | 25.7 | 1.401 |
| -5 | 33.8 | 24.9 | 1.523 | 33.4 | 25.7 | 1.317 |
| -4 | 33.7 | 24.8 | 1.578 | 33.4 | 25.7 | 1.293 |
| -3 | 33.7 | 24.7 | 1.597 | 33.4 | 25.6 | 1.333 |
| -2 | 33.7 | 24.6 | 1.675 | 33.4 | 25.6 | 1.291 |
| -1 | 33.7 | 24.6 | 1.615 | 33.4 | 25.5 | 1.274 |
| 0 | 33.7 | 24.6 | 1.537 | 33.3 | 25.5 | 1.232 |
| 1 | 33.6 | 24.4 | 1.675 | 33.4 | 25.5 | 1.216 |
| 2 | 33.6 | 24.4 | 1.675 | 33.4 | 25.4 | 1.247 |
| 3 | 33.6 | 24.4 | 1.675 | 33.3 | 25.5 | 1.186 |
| 4 | 33.6 | 24.5 | 1.594 | 33.4 | 25.5 | 1.178 |
| 5 | 33.6 | 24.5 | 1.594 | 33.4 | 25.5 | 1.186 |
| 6 | 33.7 | 24.7 | 1.467 | 33.4 | 25.6 | 1.137 |
| 7 | 33.8 | 24.8 | 1.418 | 33.6 | 25.6 | 1.145 |
| 8 | 33.9 | 25.0 | 1.313 | 33.7 | 25.6 | 1.172 |
| 9 | 34.0 | 25.1 | 1.273 | 33.8 | 25.6 | 1.194 |
| 10 | 34.2 | 25.2 | 1.249 | 34.0 | 25.5 | 1.247 |
| 11 | 34.3 | 25.3 | 1.179 | 34.0 | 25.6 | 1.164 |
| 12 | 34.4 | 25.3 | 1.192 | 34.2 | 25.8 | 1.134 |
| 13 | 34.4 | 25.3 | 1.192 | 34.3 | 26.0 | 1.087 |
| 14 | 34.5 | 25.4 | 1.159 | 34.3 | 26.1 | 1.063 |
| 15 | 34.5 | 25.5 | 1.146 | 34.3 | 26.1 | 1.049 |
| 16 | 34.6 | 25.5 | 1.159 | 34.4 | 26.1 | 1.047 |
| 17 | 34.7 | 25.5 | 1.172 | 34.5 | 26.2 | 1.034 |
| 18 | 34.8 | 25.6 | 1.141 | 34.6 | 26.3 | 1.027 |
| 19 | 34.8 | 25.6 | 1.141 | 34.5 | 26.5 | 0.968 |
| 20 | 34.8 | 25.7 | 1.099 | 34.6 | 26.6 | 0.942 |
| 21 | 34.9 | 25.7 | 1.111 | 34.7 | 26.7 | 0.925 |
| 22 | 34.9 | 25.7 | 1.111 | 34.7 | 26.8 | 0.887 |
| 23 | 34.9 | 25.7 | 1.111 | 34.7 | 26.7 | 0.921 |
| 24 | 35.0 | 25.7 | 1.153 | 34.8 | 26.6 | 0.952 |
| 25 | 35.0 | 25.7 | 1.153 | 34.8 | 26.6 | 0.962 |
| 26 | 35.1 | 25.8 | 1.123 | 34.8 | 26.6 | 0.921 |
| 27 | 35.1 | 25.8 | 1.123 | 34.9 | 26.6 | 0.940 |
| 28 | 35.1 | 25.8 | 1.123 | 34.9 | 26.6 | 0.936 |
| 29 | 35.1 | 25.8 | 1.123 | 35.0 | 26.5 | 0.956 |
| 30 | 35.2 | 25.8 | 1.135 | 35.0 | 26.4 | 1.012 |

Table A5 M O P P 3 (continued)

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| 31 | 35.2 | 25.7 | 1.147 | 35.0 | 26.4 | 1.006 |
| 32 | 35.2 | 25.7 | 1.147 | 35.0 | 26.3 | 1.028 |
| 33 | 35.2 | 25.7 | 1.147 | 34.9 | 26.4 | 0.978 |
| 34 | 35.2 | 25.7 | 1.147 | 35.0 | 26.4 | 0.981 |
| 35 | 35.2 | 25.7 | 1.147 | 34.9 | 26.4 | 0.980 |
| 36 | 35.2 | 25.7 | 1.147 | 34.9 | 26.3 | 1.002 |
| 37 | 35.3 | 25.7 | 1.159 | 34.9 | 26.4 | 0.994 |
| 38 | 35.3 | 25.8 | 1.118 | 34.9 | 26.3 | 1.012 |
| 39 | 35.3 | 25.8 | 1.118 | 34.9 | 26.5 | 0.970 |
| 40 | 35.4 | 25.8 | 1.130 | 35.0 | 26.6 | 0.948 |
| 41 | 35.3 | 25.7 | 1.130 | 35.0 | 26.5 | 0.985 |
| 42 | 35.4 | 25.6 | 1.184 | 35.0 | 26.4 | 0.996 |
| 43 | 35.4 | 25.6 | 1.184 | 35.0 | 26.5 | 1.002 |
| 44 | 35.3 | 25.6 | 1.172 | 35.0 | 26.6 | 1.033 |
| 45 | 35.3 | 26.1 | 0.983 | 35.0 | 26.8 | 0.879 |
| +1 | 35.3 | 26.1 | 1.033 | 34.9 | 26.8 | 0.899 |
| +2 | 35.3 | 25.9 | 1.106 | 34.8 | 26.5 | 0.967 |
| +3 | 35.2 | 26.0 | 1.057 | 34.6 | 26.2 | 1.047 |
| +4 | 35.1 | 26.0 | 1.046 | 34.5 | 25.9 | 1.154 |
| +5 | 35.0 | 25.8 | 1.110 | 34.3 | 25.7 | 1.208 |
| +6 | 34.9 | 25.6 | 1.180 | 34.2 | 25.5 | 1.239 |
| +7 | 34.8 | 25.4 | 1.258 | 34.2 | 25.5 | 1.262 |
| +8 | 34.7 | 25.3 | 1.294 | 34.1 | 25.4 | 1.314 |
| +9 | 34.6 | 25.3 | 1.280 | 34.3 | 25.3 | 1.411 |
| +10 | 35.0 | 25.4 | 1.285 | 34.0 | 25.5 | 1.281 |

Table A6 M O P P 4

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| -10 | 33.9 | 25.3 | 1.253 | 33.4 | 25.9 | 1.360 |
| -9 | 33.9 | 25.2 | 1.307 | 33.4 | 25.9 | 1.360 |
| -8 | 33.8 | 25.2 | 1.292 | 33.5 | 25.9 | 1.366 |
| -7 | 33.9 | 25.1 | 1.364 | 33.5 | 25.6 | 1.424 |
| -6 | 33.9 | 25.1 | 1.364 | 33.4 | 25.3 | 1.542 |
| -5 | 33.9 | 25.0 | 1.424 | 33.4 | 25.2 | 1.565 |
| -4 | 33.9 | 25.0 | 1.424 | 33.4 | 25.4 | 1.450 |
| -3 | 33.9 | 24.9 | 1.489 | 33.4 | 25.3 | 1.446 |
| -2 | 33.9 | 24.9 | 1.489 | 33.3 | 25.3 | 1.426 |
| -1 | 33.9 | 24.9 | 1.441 | 33.3 | 25.3 | 1.391 |
| 0 | 33.8 | 25.0 | 1.298 | 33.3 | 25.4 | 1.265 |
| 1 | 33.8 | 24.9 | 1.356 | 33.4 | 25.5 | 1.253 |
| 2 | 33.8 | 25.0 | 1.298 | 33.3 | 25.5 | 1.161 |
| 3 | 33.8 | 25.0 | 1.340 | 33.4 | 25.5 | 1.190 |
| 4 | 33.8 | 25.1 | 1.283 | 33.4 | 25.6 | 1.171 |
| 5 | 33.9 | 25.2 | 1.244 | 33.4 | 25.4 | 1.223 |
| 6 | 34.0 | 25.2 | 1.258 | 33.5 | 25.4 | 1.264 |
| 7 | 34.1 | 25.2 | 1.273 | 33.6 | 25.5 | 1.240 |
| 8 | 34.2 | 25.3 | 1.235 | 33.8 | 25.6 | 1.182 |
| 9 | 34.4 | 25.4 | 1.212 | 33.9 | 25.9 | 1.087 |
| 10 | 34.5 | 25.5 | 1.146 | 34.1 | 26.0 | 1.091 |
| 11 | 34.7 | 25.6 | 1.128 | 34.2 | 26.0 | 1.096 |
| 12 | 34.8 | 25.7 | 1.128 | 34.3 | 26.1 | 1.065 |
| 13 | 34.8 | 25.8 | 1.059 | 34.3 | 26.1 | 1.052 |
| 14 | 34.9 | 25.9 | 1.059 | 34.3 | 26.2 | 1.022 |
| 15 | 35.0 | 25.9 | 1.071 | 34.4 | 26.3 | 1.002 |
| 16 | 35.0 | 26.0 | 1.033 | 34.4 | 26.5 | 0.951 |
| 17 | 35.1 | 26.0 | 1.044 | 34.4 | 26.6 | 0.907 |
| 18 | 35.1 | 26.0 | 1.044 | 34.5 | 26.7 | 0.900 |
| 19 | 35.1 | 26.0 | 1.044 | 34.5 | 26.7 | 0.889 |
| 20 | 35.2 | 26.0 | 1.056 | 34.6 | 26.8 | 0.879 |
| 21 | 35.2 | 26.0 | 1.056 | 34.6 | 26.8 | 0.856 |
| 22 | 35.3 | 26.0 | 1.067 | 34.7 | 26.9 | 0.869 |
| 23 | 35.3 | 26.0 | 1.067 | 34.7 | 26.9 | 0.876 |
| 24 | 35.3 | 26.0 | 1.042 | 34.7 | 26.9 | 0.870 |
| 25 | 35.3 | 26.0 | 1.042 | 34.7 | 26.7 | 0.895 |
| 26 | 35.4 | 25.9 | 1.090 | 34.7 | 26.7 | 0.908 |
| 27 | 35.4 | 25.9 | 1.090 | 34.8 | 26.6 | 0.940 |
| 28 | 35.4 | 26.0 | 1.053 | 34.8 | 26.6 | 0.944 |
| 29 | 35.4 | 26.0 | 1.053 | 34.9 | 26.6 | 0.945 |
| 30 | 35.4 | 26.0 | 1.053 | 34.9 | 26.4 | 0.978 |

Table A6 M O P P 4 (continued)

| minute | Sea Level | | | Altitude | | |
|--------|-----------|------|-------|----------|------|-------|
| | Tsk | Tcl | I cl | Tsk | Tcl | I cl |
| 31 | 35.4 | 26.0 | 1.053 | 34.9 | 26.4 | 0.982 |
| 32 | 35.4 | 26.0 | 1.053 | 34.8 | 26.2 | 1.001 |
| 33 | 35.4 | 25.9 | 1.064 | 34.8 | 26.2 | 1.012 |
| 34 | 35.5 | 25.9 | 1.076 | 34.8 | 26.2 | 0.999 |
| 35 | 35.5 | 25.9 | 1.076 | 34.8 | 26.3 | 0.984 |
| 36 | 35.5 | 25.9 | 1.076 | 34.8 | 26.3 | 0.992 |
| 37 | 35.5 | 25.9 | 1.102 | 34.9 | 26.3 | 0.993 |
| 38 | 35.5 | 26.0 | 1.064 | 34.8 | 26.4 | 0.967 |
| 39 | 35.5 | 26.0 | 1.064 | 34.9 | 26.4 | 0.950 |
| 40 | 35.5 | 26.0 | 1.064 | 34.8 | 26.6 | 0.918 |
| 41 | 35.5 | 25.9 | 1.102 | 34.9 | 26.7 | 0.907 |
| 42 | 35.5 | 25.9 | 1.102 | 34.9 | 26.7 | 0.911 |
| 43 | 35.5 | 25.9 | 1.076 | 34.9 | 26.7 | 0.920 |
| 44 | 35.6 | 25.9 | 1.087 | 34.9 | 26.7 | 0.913 |
| 45 | 35.6 | 26.1 | 1.015 | 34.9 | 26.9 | 0.868 |
| +1 | 35.6 | 26.0 | 1.103 | 34.9 | 26.8 | 0.947 |
| +2 | 35.5 | 26.0 | 1.092 | 34.8 | 26.6 | 0.987 |
| +3 | 35.5 | 25.9 | 1.130 | 34.7 | 26.4 | 1.044 |
| +4 | 35.4 | 25.9 | 1.118 | 34.6 | 26.1 | 1.150 |
| +5 | 35.3 | 25.7 | 1.218 | 34.5 | 25.7 | 1.273 |
| +6 | 35.2 | 25.7 | 1.205 | 34.4 | 25.4 | 1.349 |
| +7 | 35.1 | 25.6 | 1.237 | 34.3 | 25.3 | 1.406 |
| +8 | 35.1 | 25.6 | 1.237 | 34.2 | 25.2 | 1.460 |
| +9 | 35.1 | 25.5 | 1.285 | 34.1 | 25.4 | 1.401 |
| +10 | 35.2 | 25.6 | 1.284 | 34.4 | 25.4 | 1.464 |

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